PROTOCOL FOR THE REDUCTION OF NOx THROUGH THE USE OF VEKTRON® 6913 GASOLINE ADDITIVE

PROTOCOL:
Infineum USA L.P.

August 2000

Proposal

Infineum USA L.P. has developed a gasoline additive package, Vektron® 6913. Through an extensive fleet test program, Vektron 6913 has demonstrated the ability to reduce Oxides of Nitrogen (NOx) emissions from passenger cars and light duty trucks to the satisfaction of the US EPA. Vektron 6913 is a combination of conventional detergent components, aromatic solvents, and a polyoxyalkylate component, Vektron® 1200, which is patented by Infineum. The detergent in the Vektron 6913 additive package keeps fuel injectors and intake valves clean to at least the level regulated by the federal government (the Clean Air Act Amendments of 1990, Section 211(L)).

Acting with the collaboration and the direction of the US EPA Office of Transportation and Air Quality (OTAQ) as well as with the advice of four major automobile manufacturers, Infineum has executed a passenger car and light duty truck fleet test program intended to validate and quantify any NOx reductions achieved through the use of Vektron 6913 versus a low sulfur California RFG II (without oxygenate) reference fuel containing a conventional detergent. An analysis of the emissions data has indicated a 10% reduction in NOx emissions without any negative impact on other criteria pollutants (CO, HC) or fuel economy (CO2). The US EPA technical review team is of the opinion that the use of Vektron 6913 at a treat rate of 234 PTB results in a 10% reduction in NOx emissions.

On this basis, it is proposed that the commercial use of Vektron 6913 in base gasoline can result in the reduction of NOx versus the local baseline NOx emissions from passenger cars and light duty trucks. Local baseline NOx emissions being defined as NOx emissions which would occur in the absence of Vektron 6913. Since Vektron 6913 NOx emissions reductions are surplus to those regulated under current US EPA fuel and additive rules, it is also proposed that NOx reductions achieved through the commercial use of Vektron 6913 be incorporated into the US EPA's Economic Incentives Program as emissions reduction credits and voluntary measures.

This document details the methodology for generating and quantifying the proposed mobile source Vektron 6913 NOx emissions reductions.

"Real, Surplus" Determination

An analysis of the Vektron 6913 fleet test data has indicated a NOx emissions benefit even when tested against conventional detergent additives which act to keep fuel injectors and valves clean. Even though US EPA imposed regulations under the Clean Air Act effective 1/l/95 which makes the use of conventional detergents to keep injectors and intake valves clean mandatory for all gasoline, the NOx emissions benefits provided by this technology are over and above this regulation. Hence, the extra benefit provided by Vektron 6913 is surplus to the regulated levels.

Background

In July of 1997, a “Protocol for the Reduction of NOx. Through the Use of Vektron 3000 Gasoline Additive” was submitted for approval to the State of New Hampshire, Department of Environmental Services, Air Resources Division. Following several weeks of public comment, The State of New Hampshire’s response was that, while NOx reductions were indicated through the use of Vektron 3000, the quantification of those reductions was not conclusive. The State of New Hampshire recommended that a more definitive fleet test program was necessary to further demonstrate and quantify Vektron 3000’s NOx reductions.

Following New Hampshire’s response, Infineum entered into several months of collaboration with the US EPA Office of Transportation and Air Quality (OTAQ), with input and advice from major automotive manufacturers, on the design and execution of a passenger car and light duty truck fleet program. This program was intended to validate and quantify the NOx reductions achieved through the use of Vektron 6913 gasoline additive to the satisfaction of OTAQ. Vektron 6913 is similar to Vektron 3000, containing the same chemical components but at a different concentrations.

The resulting test design, referred to as The Vektron 6913 Fleet Test in this document, included 28 vehicles representing a large cross-section of the US passenger vehicle fleet. Details on the test program can be found in the document titled “ Vektron 6913 Gasoline Additive NOx Evaluation Fleet Test Program” and a report from Southwest Research Institute. Each vehicle was tested for the criteria pollutants and CO_2 using three different cycles at the beginning and end of each mileage accumulation.

Vektron 6913 Fleet Test Design

With the advice and collaboration of the US EPA OTAQ and automotive manufacturers, the Vektron 6913 fleet test was designed to represent a realistic cross-section of the current and near future (through inclusion of low emissions vehicles and California RFG Phase 2 base gasoline) U.S. gasoline powered passenger car and light duty truck fleet. Southwest Research Institute in San Antonio, Texas conducted the test. Test mileage accumulation of 8,000 miles is average for a typical “ozone” season.

A summary description of each variable in the Vektron 6913 fleet test design follows:

Vehicle Representation

The Vektron 6913 Fleet Test was designed to represent the current and near future US fleet of gasoline powered passenger cars and light duty trucks, in terms of sales. The vehicles were selected based on US sales volume and ranged in model years from 1994 through 1999. They included passenger cars and light duty trucks (SUVs and pick-ups) of differing engine sizes (1.9 to 5.7 L, I-4 to V-8). The test also included 8 low emission vehicles (LEVs), the 1999 Ford Explorers and 1998 Honda Accords, to represent the changing emissions standards of the US vehicle fleet. All vehicles had accumulated varying levels of odometer mileage prior to testing (18,000 – 105,000 miles).

The Vektron 6913 Fleet Test also included a qualification test on oil consumption and regulated emissions on each vehicle in the test to control selection to vehicles within normal operating range (i.e., no oil burners or high emissions emitting vehicles) based on recommendations from the US EPA and major vehicle OEMs.

Vehicles selected for The Vektron 6913 Fleet Test were based on the consensus view of the US EPA, major automotive OEMs, and Infineum such that any NOx reductions shown in this fleet test could be applied directly to the larger U.S. gasoline powered passenger car and light duty truck fleet.

Fuel

At the suggestion of US EPA, the unadditized base fuel chosen for the Vektron 6913 Fleet Test was specially blended for this test to represent California RFG Phase 2 gasoline with additional specifications of low sulfur and no oxygenates. It is believed that this gasoline represents the direction of future US gasoline.

In order to produce fuel with minimum deposit forming tendencies and to remain within commercial limits, the parameters used by the US EPA in the regulations supporting the Clean Air Act Amendments of 1990, Section 211(l), to determine fuel deposit forming severity were specified. In order to meet these specifications, a regular grade octane was not achievable. Since the US EPA does not recognize octane as a fuel deposit forming severity factor, the octane was only specified to meet minimum commercial limits. The octane ((R+M)/2) of the unadditized base fuel was 90.2 making it a mid-grade gasoline.

Because California RFG Phase 2 gasoline is considered to be one of the “cleanest” gasolines available from an emissions standpoint, it was judged in consultation with the US EPA that any NOx benefit quantification demonstrated in the fleet test can be applied to any US produced gasoline containing Vektron 6913 gasoline additive.

Additives

Two fuels were used in the Vektron 6913 Fleet Test:

Reference fuel	Unadditized fuel + 154 PTB Vektron 2864*
Test fuel	Unadditized fuel + 234 PTB Vektron 6913

(PTB= Pounds of additive per thousand barrels of gasoline) (*Vektron 2864 has been rebranded Infineum F7721)

The Vektron 2864 is a conventional gasoline detergent additive package. The Vektron 6913 package contains Infineum's patented Vektron 1200 component in place of the synthetic carrier present in Vektron 2864. However, each fuel delivered the same detergent component and the same concentration of detergent in this fleet test. This was done to isolate the impact of Vektron 1200 on emissions and eliminate any impact that poor detergency could potentially have on emissions.

Fuel Switching

The Vektron 6913 Fleet Test design includes a fleet test component of mileage accumulation with alternating fuel. Alternating fuel is defined as switching between reference fuel and test fuel at each fuelling point during the mileage accumulation. This fuel switching was meant to represent consumer brand switching between Vektron additized gasoline and conventionally additized gasoline. Because it is difficult to test all possible consumer purchasing patterns, it was agreed with the US EPA and the OEMs that the alternating fuel switching scheme used in this fleet test was representative enough to quantify the effect of brand switching between Vektron additized gasoline and conventionally additized gasoline.

Comparison of the NOx results from the alternating fueling scheme to the NOx results from the continuous use of test fuel scheme, would give an indication of the impact of consumer brand switching on any overall NOx reductions.

Mileage Accumulation

Mileage accumulation during the Vektron 6913 Fleet Test was controlled and consistent for every vehicle and every run. Each run duration was 8,000 miles to approximate the total mileage that an average vehicle could accumulate during a typical ozone season. Each vehicle ran no more than 16 hours per day with an 8 hour soak time, as accepted by the US EPA and the California Air Resource Board (CARB) in previous Coordinating Research Council (CRC) programs. In addition, no vehicle was out of service for longer than a 2-day period.

The mileage accumulation cycle was performed according to 40 CFR Ch. 1 (7-1-94 Edition) § 86.084-26 (Appendix 2) and as modified in the Mobile Source Air Pollution Control (MSAPC) Advisory Circular A/C No. 37-A driving mode 70 mph top speed.

Emissions Testing

At the suggestion of US EPA, in the Vektron 6913 Fleet Test each vehicle was tested using FTP-75, US06 and Highway Fuel Economy Test (HFET) cycles. Regulated emissions (NOx, CO, HC) were tested in duplicate. Additional tests were run if necessary as judged using the CRC Auto / Oil Protocol.

Vektron 6913 Fleet Test Summary Results

Details on the test program summary results and analysis of results can be found in the document entitled " Vektron 6913 Fleet Test Experimental Design and Analysis". In summary, an analysis of the Vektron 6913 fleet test emissions data has indicated that, the inclusion of Vektron 6913 into a California RFG Phase 2 (without oxygenate) base gasoline at a treat rate of 234 PTB can yield NOx reductions (versus California RFG Phase 2 gasoline with an additive package certified for Clean Air Act Section 211 (L), but without oxygenate) of:

(1) 10% when used continuously over 8,000 miles
(2) 10% when used in an alternating fashion (tank of test fuel, tank of reference fuel) over 8,000 miles.

Also, the Vektron 6913 fleet test has indicated that, the inclusion of Vektron 6913 into a California RFG Phase 2 (without oxygenate) gasoline does not have a deleterious impact on HC, CO, or fuel economy compared to California RFG Phase 2 gasoline with CAA 211(L)-certified detergent.

Vektron 6913 NOx Reduction Benefit Application To The Local or National Fleet

To apply the percent (%) NOx reduction benefits indicated from the Vektron 6913 fleet test to the larger local or U.S. gasoline powered passenger car and light duty truck population requires generating an estimate of NOx generation from those two mobile sources in the larger local or U.S. fleet, i.e. determining a "baseline", such that:

(1) (% NOx reduced) * (Local or U.S. "baseline", tons NOx produced per million gallons of gasoline) = Tons NOx reduced per million gallons of Vektron 6913 additized gasoline consumed

Determination of Local or U.S. Baseline (NOx tons produced per million gallons of gasoline)

Since NOx emissions baseline rates are generally expressed in NOx grams per mile, and only passenger cars and light duty trucks are considered for this baseline analysis, it is necessary to calculate composite passenger car and light duty truck baseline NOx emissions rates (NOx grams per mile), and composite passenger car and light duty truck gasoline fuel economy (miles per gallon) such that:

(2) Local or U.S. Baseline, NOx tons produced per million gallons of gasoline =
(Local or U.S. Composite Light Duty Truck +Passenger Car Baseline)*(Local or U.S. Composite Light Duty Truck +Passenger Car Mileage)*(Conversion Factor)

Where:

Local or U.S. Composite Light Duty Truck +Passenger Car Baseline = Local or U.S. NOx emissions from light duty trucks and passenger cars if the Vektron additized gasoline strategy is NOT employed = NOx grams per mile

Local or U.S. Composite Light Duty Truck +Passenger Car Mileage = Local or U.S. gasoline fuel economy from light duty trucks and passenger cars = miles per gallon

Conversion Factor = Factor to convert NOx grams produced per mile to tons of NOx produced per 1 million gallons of gasoline consumed =1,000,000 gallons ÷ 453.59 gms per lb ÷ 2000 lbs per U.S. ton = 1.102 tons-gallons/gm-million gallons

Calculating local or U.S. Composite Light Duty Truck + Passenger Car Baselines (NOx gms per mile) and Mileages (miles per gallon) requires the following information be known:

- Average annual NOx emissions rate for passenger cars (NOx gm per mile) = NOx_{PC}
- Average annual NOx emissions rate for light duty trucks (NOx gm per mile) = NOx_{LDT}
- Average annual fuel economy for passenger cars (miles per gallon) = FE_{PC}
- Average annual fuel economy for light duty trucks (miles per gallon) = FE_{LDT}
- Average annual mileage for passenger cars (miles) = M_{PC}
- Average annual mileage for light duty trucks (miles) = M_{LDT}
- Average annual % vehicle miles traveled by passenger cars (%) = $\%VMT_{PC}$
- Average annual % vehicle miles traveled by light duty trucks (%) = $\%VMT_{LDT}$

$\%VMT_{PC}$ and $\%VMT_{LDT}$ are normalized to reflect only %VMT by passenger cars and light duty trucks as follows:

- Normalized $\%VMT_{PC} = \%VMT_{PCN} = 1* \%VMT_{PC} \div (\%VMT_{PC} + \%VMT_{LDT})$
- Normalized $\%VMT_{LDT} = \%VMT_{LDTN} = 1* \%VMT_{LDT} \div (\%VMT_{PC} + \%VMT_{LDT})$

$\%VMT_{PCN \text{ and }} \%VMT_{LDTN \text{ are}}$ adjusted to reflect the differences in annual mileage between passenger cars (M_{PC}) and light duty trucks (M_{LDT}) as follows:

- Normalized, adjusted $\%VMT_{PC} = \%VMT_{PCNA} = \%VMT_{PCN}* M_{PC} \div (\%VMT_{PCN}* M_{PC} + \%VMT_{LDTN}* M_{LDT})$

- Normalized, adjusted $\%VMT_{LDT} = \%VMT_{LDTNA} = \%VMT_{LDTN}* M_{LDT} \div (\%VMT_{PCN}* M_{PC} + \%VMT_{LDTN}* M_{LDT})$

The Local or U.S. Baseline, NOx tons produced per million gallons of gasoline, is calculated as follows:

(3) Local or U.S. Baseline, NOx tons produced per million gallons of gasoline =

$\{(NOx_{PC})*(\%VMT_{PCNA})+(NOx_{LDT})(\%VMT_{LDTNA})\}*\boldsymbol{\{}(FE_{PC})*(\%VMT_{PCNA})+(FE_{LDT})*(\%VMT_{LDTNA})\boldsymbol{\}}*$ (1.102 tons-gallons/gm-million gallons)

Where:

NOx_{PC} = NOx emissions from Passenger Cars.
NOx_{LDT} = NOx emissions from Light Duty Trucks.
$\%VMT_{PCNA}$= % vehicle miles traveled by passenger cars, normalized to reflect %VMT (Passenger Cars + Light Duty Trucks)= 100%, and adjusted to reflect differences in annual mileages between passenger cars and light duty trucks.
$\%VMT_{LDTNA}$= % vehicle miles traveled by light duty trucks, normalized to reflect %VMT (Passenger Cars + Light Duty Trucks)= 100%, and adjusted to reflect differences in annual mileages between passenger cars and light duty trucks.
FE_{PC}= Fuel economy, miles per gallon, passenger cars.
FE_{LDT} = Fuel economy, miles per gallon, light duty trucks.
Conversion factor, to convert NOx gm per mile to NOx tons per million gallons of gasoline consumed = 1.102 tons-gallons/gm-million gallons

Example of Calculation of Local or U.S. NOx Baseline

Per US EPA 420-F-00-013, April, 2000, "Emissions Facts- Average Annual Emissions and Fuel Consumption for Passenger Cars and Light Trucks":

- Average annual NOx emissions rate for passenger cars (NOx gm per mile) = NOx_{PC} = 1.39 gm/mi
- Average annual NOx emissions rate for light duty trucks (NOx gm per mile) = NOx_{LDT} = 1.81 gm/mi
- Average annual fuel economy for passenger cars (miles per gallon) = FE_{PC} = 21.51 mi/gal
- Average annual fuel economy for light duty trucks (miles per gallon) = FE_{LDT} = 17.22 mi/gal
- Average annual mileage for passenger cars (miles) = M_{PC} = 12,500 miles
- Average annual mileage for light duty trucks (miles) = M_{LDT} = 14,000 miles

Based on the Mobile 5 model and current U.S. vehicle sales figures:

- Average annual % vehicle miles traveled by passenger cars (%) = $\%VMT_{PC}$ = 58.4%
- Average annual % vehicle miles traveled by light duty trucks (%) = $\%VMT_{LDT}$ = 40.8%

% VMT's normalized to reflect only passenger cars and light duty trucks:

- $\%VMT_{PCN} = 1 * (58.4\%) \div (58.4\% + 40.8\%) = 58.9\%$
- $\%VMT_{LDTN} = 1 * (40.8\%) \div (58.4\% + 40.8\%) = 41.1\%$

Normalized %VMT's adjusted to reflect differing annual mileages between passenger cars and light duty trucks:

- $\%VMT_{PCNA}$ = 58.9%*12,500 miles ÷ (58.9%*12,500 miles + 41.1%*14,000 miles) = 56.1%
- $\%VMT_{LDTNA}$ = 41.1%*14,000 miles ÷ (58.9%*12,500 miles + 41.1%*14,000 miles) = 43.9%

Then by equation (3) above:

(3) Local or U.S. Baseline, NOx tons produced per million gallons of gasoline =

$\{$(1.39 gm/mi) *(56.1%)+(1.81 gm/mi)*(43.9%)$\}$* $\{$(21.51 mi/gal)*(56.1%)+(17.22 mi/gal)*(43.9%)$\}$*(1.102 tons/gm-million gallons) = 34.06 NOx tons produced per million gallons of gasoline consumed

Example of Calculation of Vektron 6913 NOx Reduction

By equation (1) above:

Tons NOx reduced per million gallons of Vektron 6913 additized gasoline consumed = (% NOx reduced) * (Local or U.S. "baseline", tons NOx produced per million gallons of gasoline consumed)

Based on an analysis of the Vektron 6913 fleet test emissions data, the inclusion of Vektron 6913 into base gasoline reduces the NOx emissions from that gasoline by 10%.

The above example calculates a U.S. NOx emissions baseline for passenger cars and light duty trucks of 34.06 NOx tons produced per million gallons of conventional additized gasoline consumed.

Therefore, in this example, NOx reduction benefits achieved through the use of Vektron 6913 additized gasoline are calculated to be:

(10%)* (34.06 NOx tons produced per million gallons of conventional gasoline) = **3.406 NOx tons per million gallons of Vektron 6913 additized gasoline.**

Discounts to Vektron 6913 NOx Reduction Benefit Application To The Local or National Fleet

In the past, various "discounts" have been taken to proposed NOx reductions to account for variables occurring in the marketplace that are unaccounted for in the test programs which lead to the generation of protocols for the marketplace. For example, the scope of vehicle types in the test program may not reflect the scope of vehicle types in the marketplace, consumer brand switching may be unaccounted for, different base fuels in the marketplace may not have been tested, etc.

A substantial effort was made by Infineum and the US EPA (supported by advice from several major automotive manufacturers) to design the Vektron 6913 Fleet Test to reflect the current and near-future passenger car and light duty truck fleets during an average ozone season (8,000 miles. Specifically,

- Test vehicles were selected to represent the highest selling vehicles in the U.S. They also represent the vast majority of emissions control technologies currently in use. The inclusion of LEV's in the test program was done with the near future fleet in mind, and to provide a substantial and robust vehicle emissions technology standard against which to demonstrate NOx reductions with a fuel additive technology.
- The "alternating" (between reference fuel and test fuel) tank component of the test was intended to provide a measure of the impact of consumer brand switching.

- The base fuel selected was one of the “cleanest” fuels available, i.e. California RFG Phase 2 (without oxygenate). While California RFG Phase 2 is not the most widely used gasoline in the U.S., it does provide a substantial and robust fuel emissions technology standard against which to demonstrate NOx reductions with a fuel additive technology.

Based on the rigor of the Vektron 6913 Fleet Test design, and the results of the “alternating” tank component of the fleet test itself, it is proposed that this NOx reduction protocol arising from the results of the Vektron 6913 Fleet Test be free of any discounting.

Verification of Vektron 6913 NOx Benefits

The aforementioned NOx benefit quantification methodology can be applied to any gasoline that can be verified to contain the correct amount of the Vektron 6913. Since the introduction of the federal regulations on the addition of detergent additives to gasoline, this has become significantly easier. Each terminal operator is required to keep monthly records on the amount of additive they have used and the amount of fuel that has been sold. These records are called Volumetric Additive Reconciliation records or VARs. If a terminal is adding Vektron 6913 to its gasoline, verification of the additive use can be achieved through these federally required records. The VARs will contain the number of gallons of gasoline that contained the additive that were sold as well as the amount of additive that was sold in the gasoline. The additive figure can be used to ensure that the correct amount of Vektron 6913 additive was used and the gasoline figure, in millions of gallons, can be used as the multiplier to calculate the emissions benefit realized.

Example:

Assume the “local” baseline NOx emissions for a given area is 34.06 NOx tons produced for every one million gallons of conventional gasoline consumed.

Assume use of Vektron 6913 additized gasoline, gives NOx emissions 10% below the “local” baseline.

Then the NOx benefit to using Vektron 6913 additized gasoline is:

(10%)*(34.06 NOx tons/million gals.) = 3.406 NOx tons per million gallons of Vektron 6913 additized gasoline.

If a “local” gasoline terminal sells 200 million gallons of gasoline containing Vektron 6913, then:

NOx Benefit = 200 x 3.406
= **681 tons of NOx**